Remote Microgrids in Canada

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Outline

- Motivations and objectives.
- Off-grid diesel-based communities in Canada.
- Optimal planning: Kasabonika Lake First Nation.
- Optimal dispatch: Bella Koola.
- Research at uWaterloo
- Conclusions.

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Motivation

- Many communities in Canada and remote communities in the rest of the world are not connected to the grid and depend on other means to supply electrical energy to their community.
- Remote communities in Northern Canada have no road access.
- The dominant source of electrical energy for these communities is through diesel fuel generator sets.
- Diesel must be supplied to these communities.
- All of the community supply comes from brief winter road access or by air.

Motivation

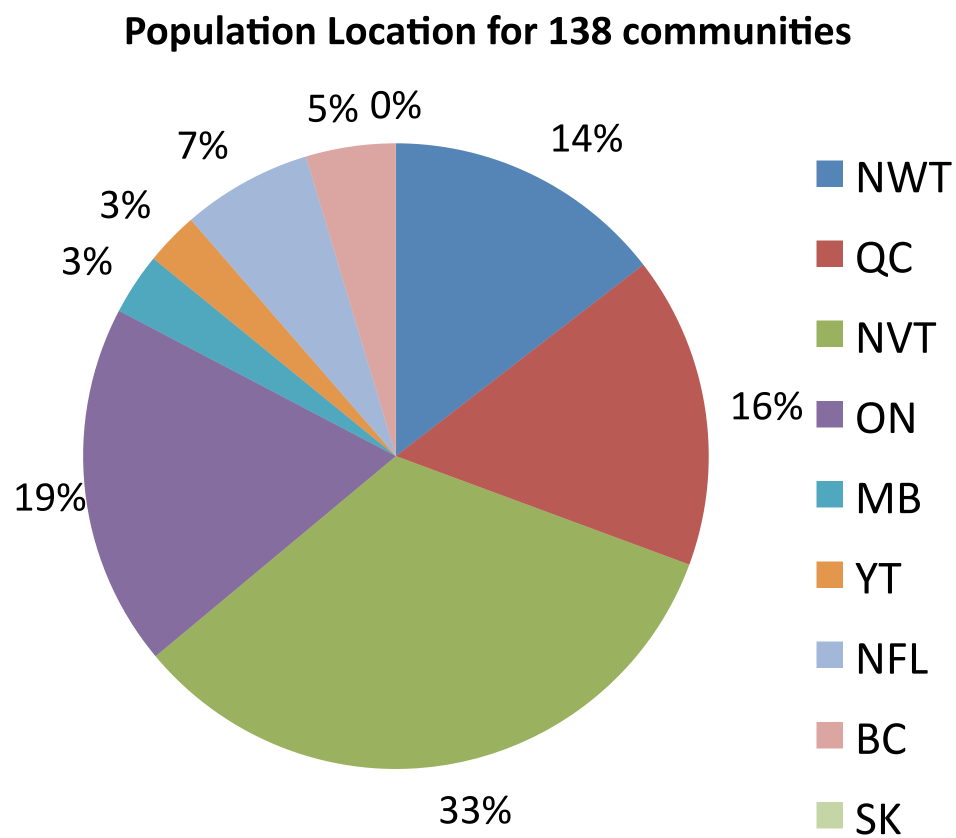
- There is then a need for clean, reliable renewable electricity in remote communities in Canada and the world.
- Energy costs and cost uncertainty need to be reduced (fuel and transportation):
  - Energy costs in remote Canadian communities can be many times greater than a grid connected community.
- Potential damage to environment from fuel transportation and emissions (gases and particles) needs to be addressed as well .

Objectives

- Determine local renewable energy (RE) sources, particularly wind, solar, hydro, biomass, most appropriate economically and technically for remote communities, considering their climatic conditions.
- Develop micro grid controller technologies to properly integrate and control multiple energy sources and storage, considering a possible eventual connection to the grid.

Remote Community Microgrids in Canada

- 175 locations using diesel for energy mix.
- Selected sample:
  - 138 communities running solely on diesel.
  - Accounts for 88,000 people.
  - 60+ communities with annual avg. wind speed above 6 m/s.



Source: Statistics Canada (2006)

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Remote Community Microgrids in Canada

- Energy capacity issues:
  - Demand reaching electrical capacity limit.
  - Communities reach load restrictions.
- Capital project issues:
  - Lack of funding for increase capacity projects.
- Logistic issues:
  - Community access solely by winter roads or plane.
- Environmental issues:
  - All energy generation produces CO_2 emissions.
  - Potential leaks while transporting and storing fuel.

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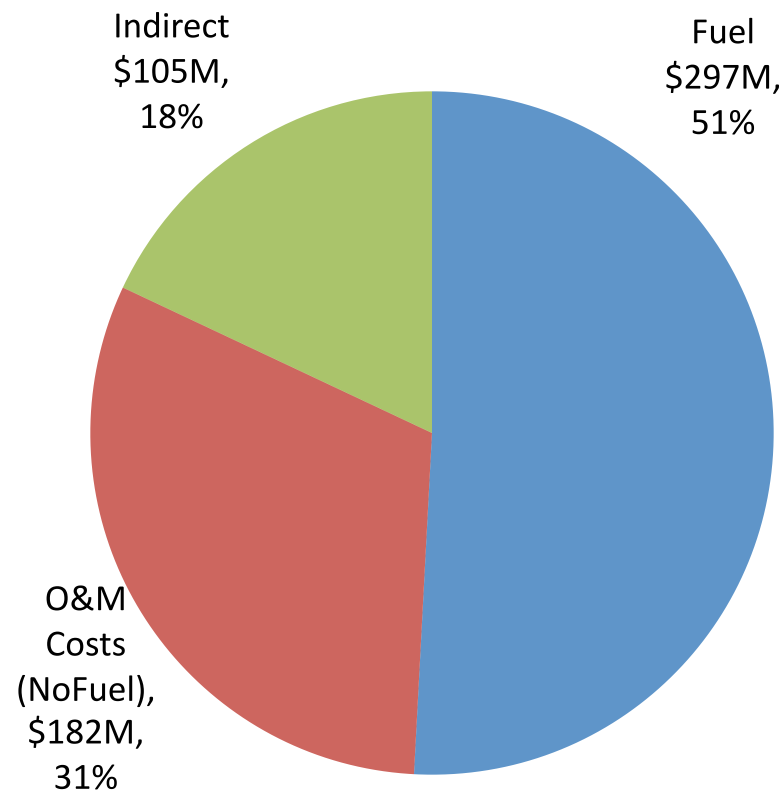
Remote Community Microgrids in Canada

- Operation and maintenance (O&M) issues:
  - High diesel-fuel and energy cost.
  - Lack of local technical experts.
- Social issues:
  - Load restrictions limit new construction.
  - Community engagement is indispensable:
    - Acceptance of new technologies is important, particularly with regards to load management.
    - Given remoteness, there is a need to develop local expertise for O&M of microgrid.

Remote Community Microgrids in Canada

- Fuel consumption: 129 million lt./year
- CO_2 emissions: 368,000 ton/year
- Total cost: $583M/year
- Energy: 459 TWh/year
- Avg. LUEC: $1.2/kWh
- Subsidies: Provincial and federal.
- Operation/owner: Provincial utilities, community utilities.



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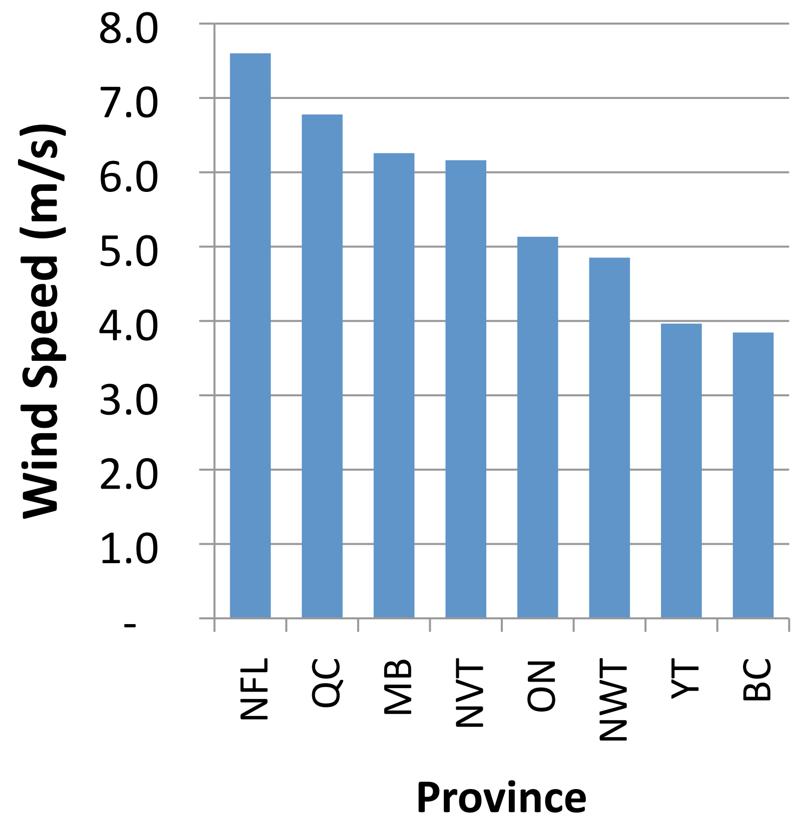
Remote Community Microgrids in Canada

- Wind resources:
  - Communities' annual average wind speed (WS):
    - 8 sites: WS > 8m/s
    - 25 sites: 7m/s ≤ WS < 8m/s
    - 28 sites: 6m/s ≤ WS < 7m/s
    - 29 sites: 5m/s ≤ WS < 6m/s
    - 48 sites: WS < 5m/s
  - Potential sites can achieve 20%-35% capacity factor.
  - Difficult to set a fixed federal incentive; a provincial approach is required.
  - Small wind relies on local wind currents difficult to be reflected in mesoscale models.



Source: Wind Atlas Canada

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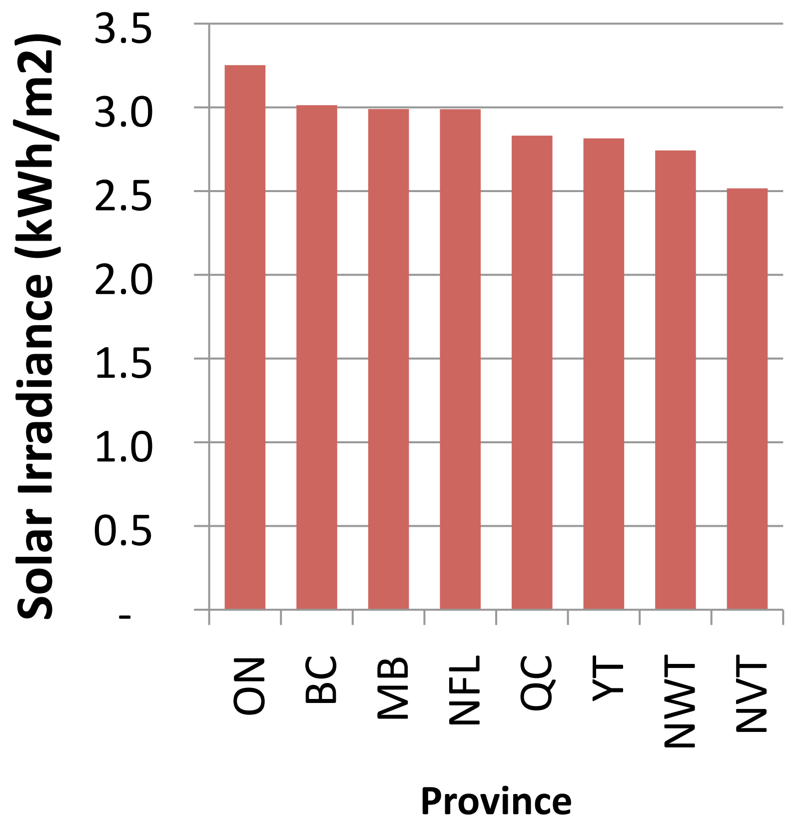
Remote Community Microgrids in Canada

- Solar Resources:
  - Potential sites can achieve a capacity factor of 8-10%.
  - Even distribution of solar resource across the country.
  - Comparison with wind resource:
    - Simpler installation & maintenance in remote communities.
    - Higher prediction accuracy of expected energy.



Source: NASA

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Kasabonika Example

Kasabonika Lake

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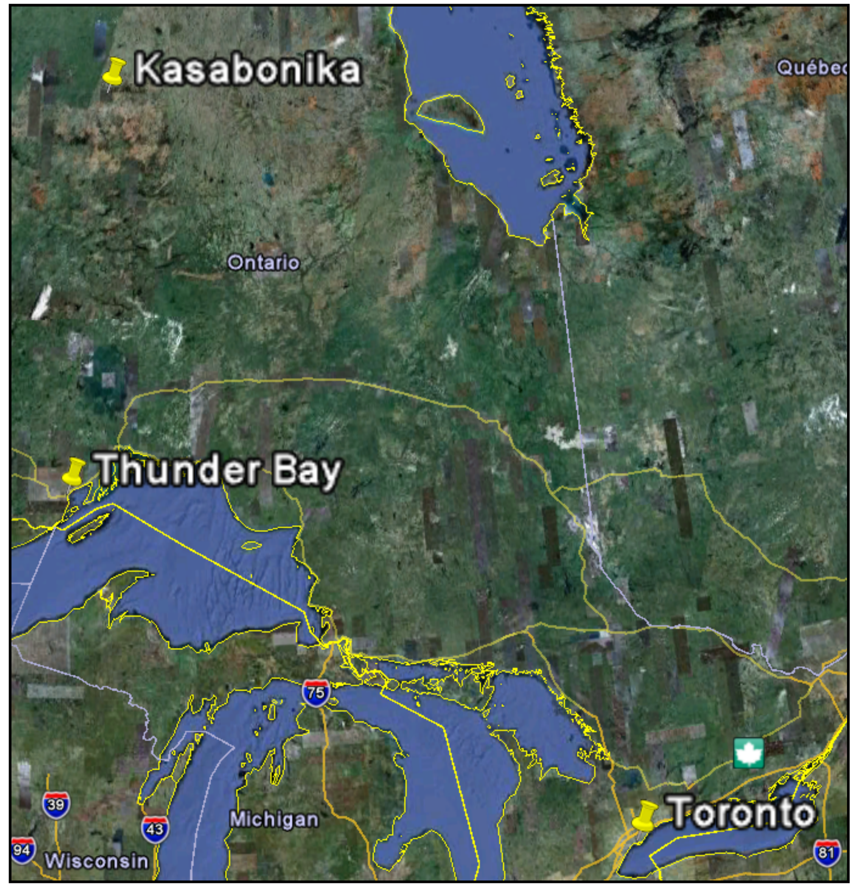
Kasabonika Example

- Population: 914 people
- Remote Location:
  - 1,300km from Toronto.
  - 500km from Thunder Bay.
- Accessibility:
  - Winter roads with load restriction:
    - 80,000lbs max. weight allowance.
    - 40,000lbs frequent restriction due to ice thickness conditions, creek crossing.
  - Plane: $1,500 round-trip from Thunder Bay



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Kasabonika Example

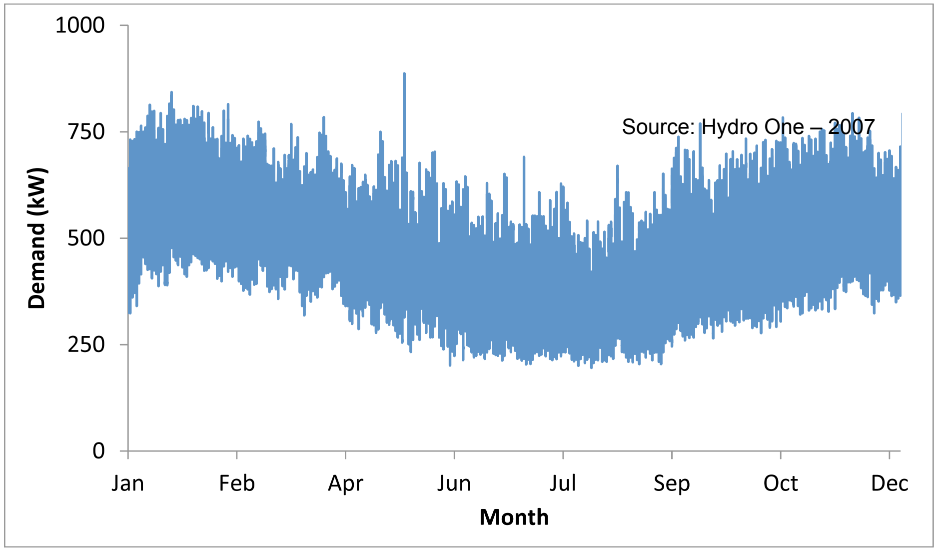
- Existent microgrid:
  - Diesel Generators: 1000, 600, 400 kW
    - Diesels have worked well for many years and are a well-known technology.
    - Many are familiar and comfortable with operational aspects.
    - Require regular attention (maintenance, service, replacement).
  - Wind turbines: 3x10kW + 1(new)x30kW

One diesel gen set

Diesel tank farm

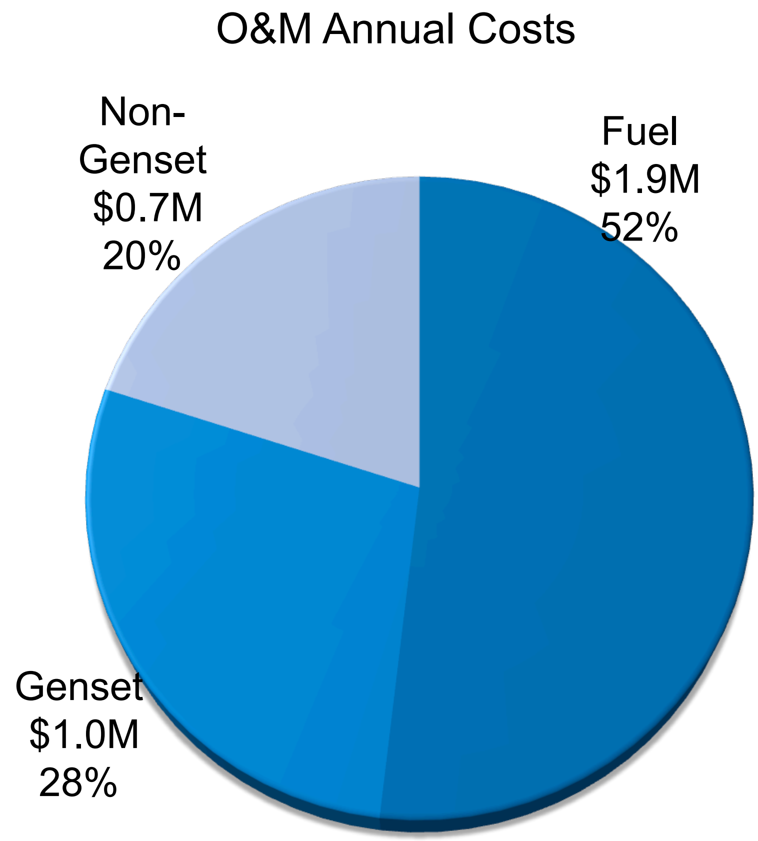
Kasabonika Example

- Electricity Demand 2007:
  - 12MWh/day
  - 850kW peak
- Fuel:
  - 1.0M-1.2M litre/year
  - 3,600 ton/year CO_2 eq.
  - $ 1.8/litre



Kasabonika Example

- Three O&M cost categories:
  - Fuel cost.
  - Gen. set related cost.
  - Non-gen. set related cost.
- Total O&M cost:
  - $3.7M/year
  - Levelized energy cost: $0.84/kWh (a residential bill in southern Ontario ~ $0.10/kWh)



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Kasabonika Example

- Electrical issues:
  - Demand has already reached 90% electrical capacity.
  - Community is in load restriction due to capacity constraint, which has social impacts.
  - Additional 1.2MW gen. set on-site, but no funding available for its installation for at least 5 years.
  - $10M Capital cost for expansion project (gen. set, 2x50,000 litre tanks, building, transformers, installation).
  - All energy generation produces CO_2.

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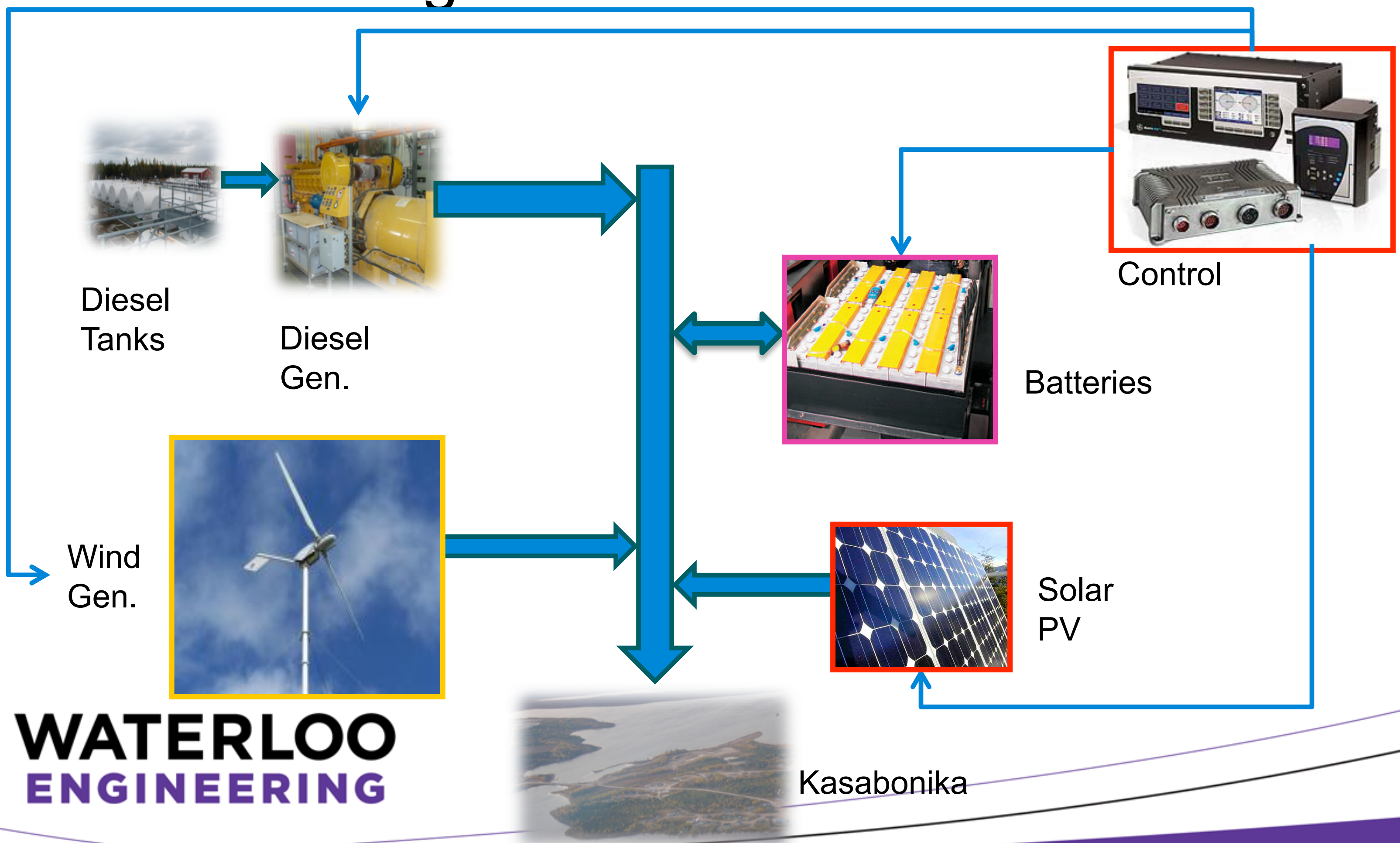
Kasabonika Example

- Desired microgrid:



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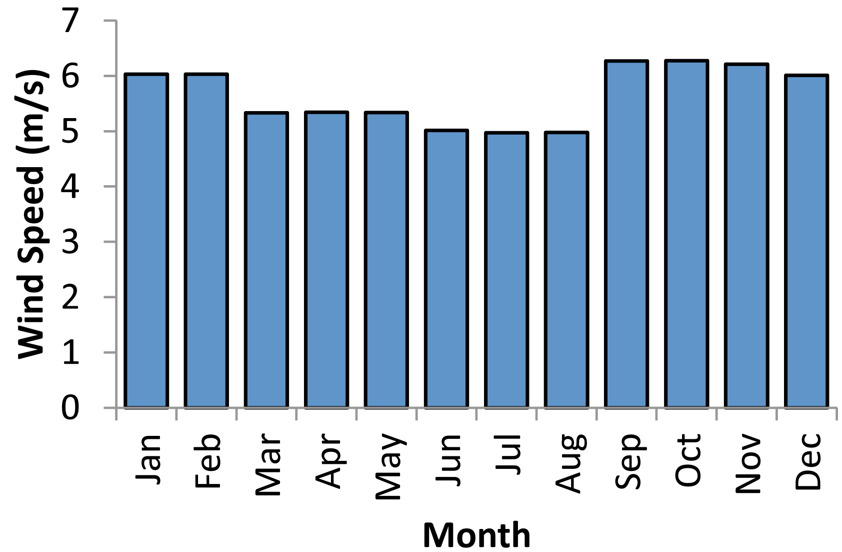
Kasabonika Example

- Wind speed estimate (Canada Wind Atlas):
  - Annual average: 5.68 m/s @ 30m
- Energy output estimate for 6x50kW WTs:
  - 436MWh/year
  - 10% of annual demand
  - 16.5% capacity factor



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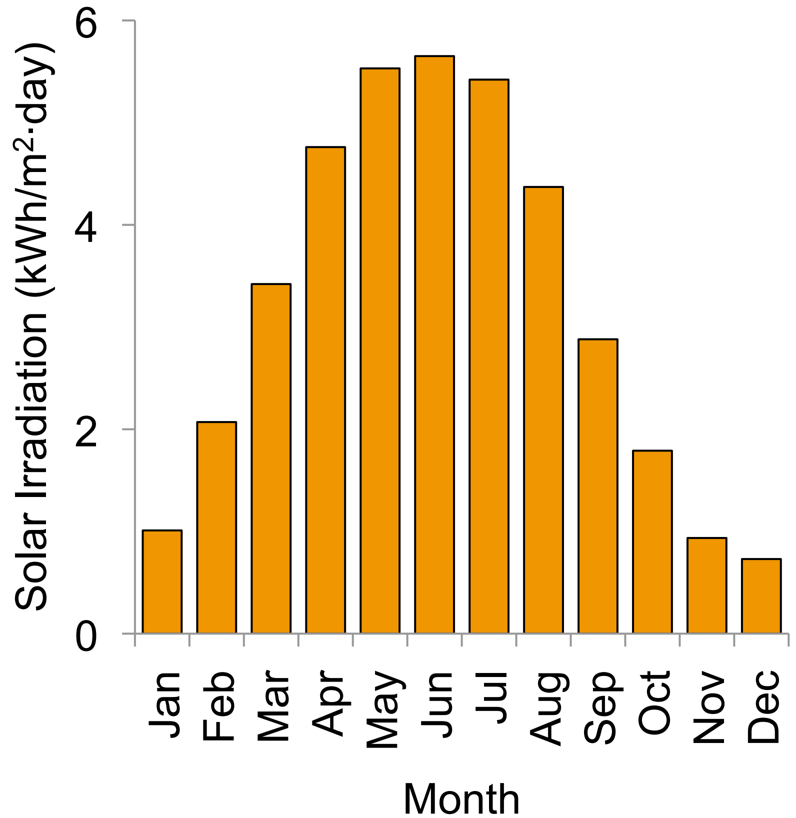
Kasabonika Example

- Solar radiation estimate (NASA):
  - Annual: 3.22 kWh/ m2·day
- Energy output estimate for 300kW PV panels:
  - 395MWh/year
  - 9% of annual demand
  - 15% capacity factor



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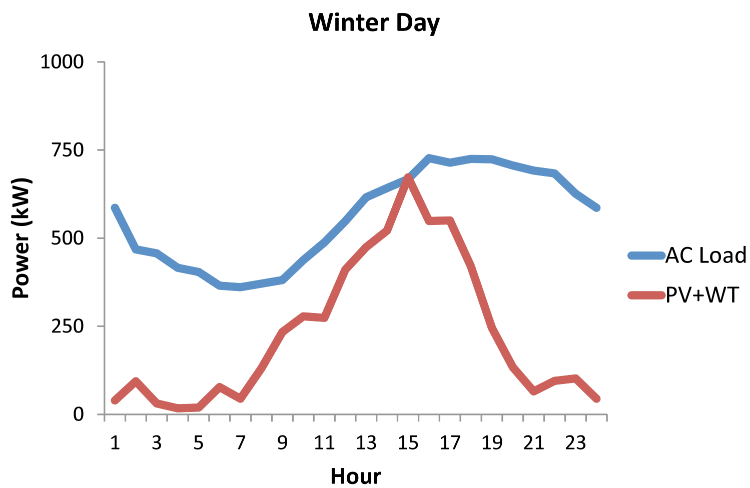

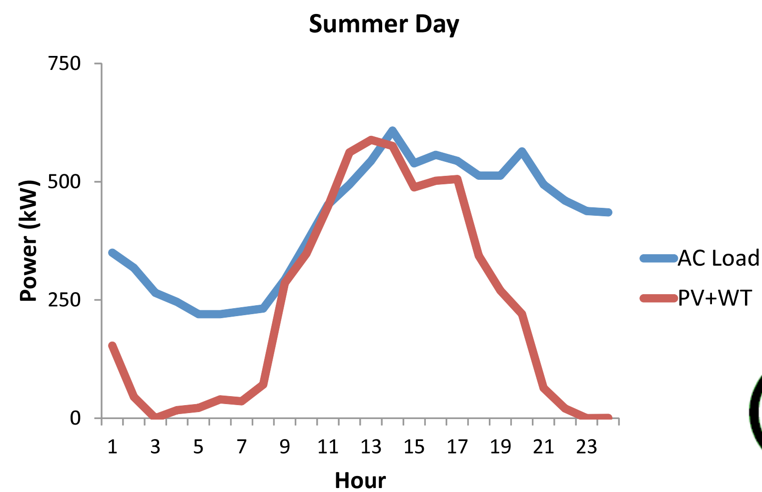

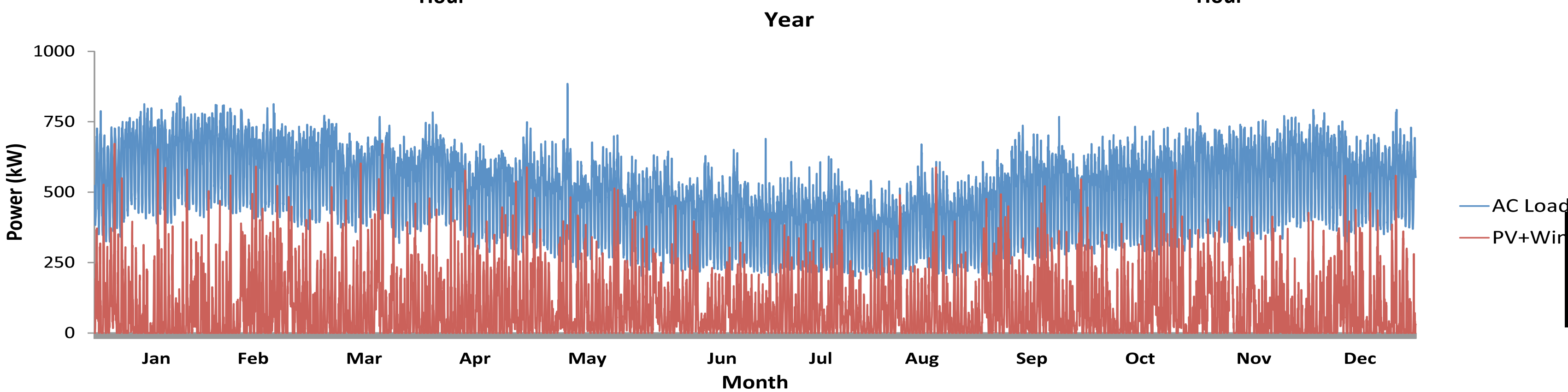

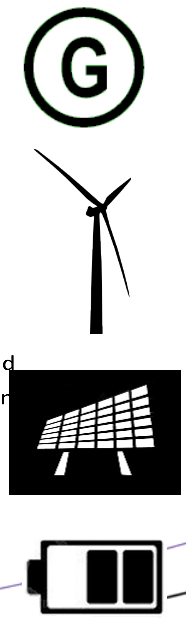

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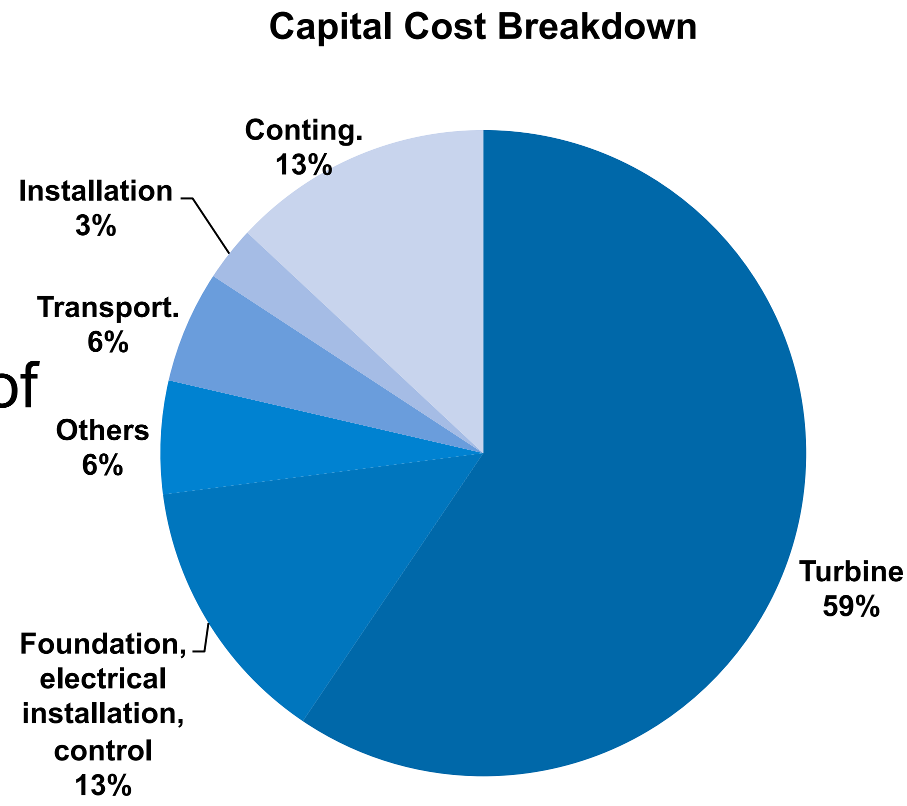
- WT cost estimate:
  - Capital cost: $9,250/ kW
  - O&M cost: $250/ kW·year 3.5% of capital cost



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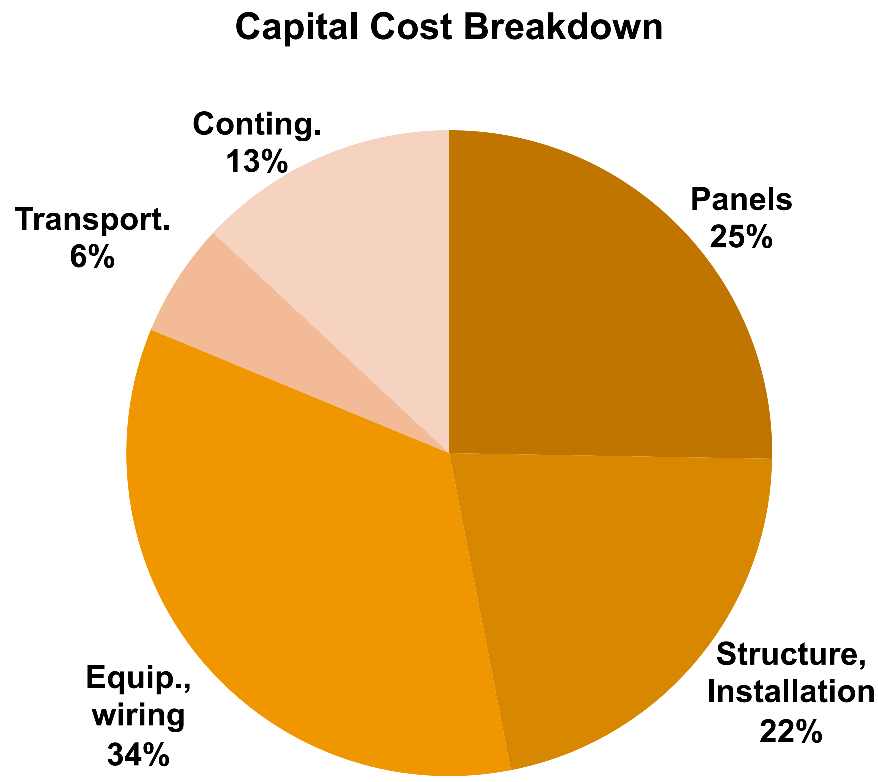
Kasabonika Example

- PV cost estimate:
  - Capital cost: $11,000/ kWp
  - O&M cost: 130/ kWp·year 1.5% of capital cost



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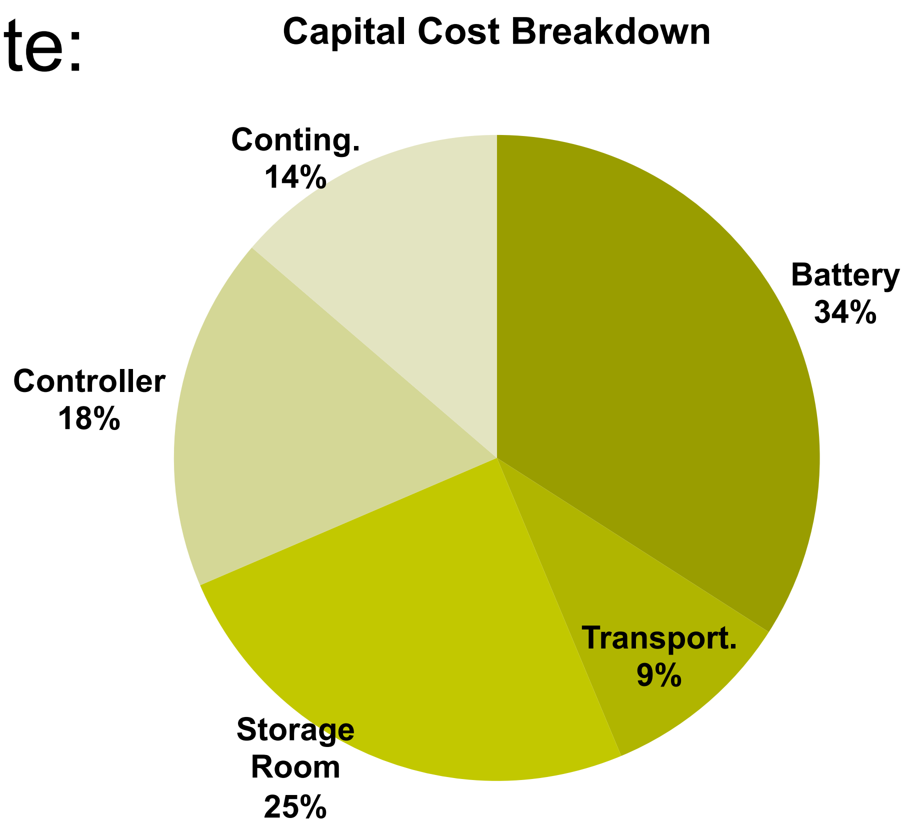
- Battery cost estimate:
  – Capital cost: $664/ kWh
  – O&M cost: $17/kWh capacity installed·year



Kasabonika Example

Description	Unit	Baseline (DGS)	PV+WT+DGS	PV+WT+Battery+DGS
System Characteristics				
RE fraction	%	-	9%	18%
DGS	#	3	3	3
PV Capacity	kW	-	250	375
WT Capacity	kW	-	100	200
Battery Capacity	kWh	-	-	53
Fuel/Emissions				
Fuel Consumption	litre x 10^6	1.07	0.96	0.89
Fuel Reduction*	litre x 10^6	-	0.10	0.17
	%	-	10%	16%
Emissions	ton	3,325	2,999	2,784
Emission Reduction*	ton	-	326	541
	%	-	10%	16%
Capital Cost				
Solar Energy	M$	-	$ 2.89	$ 4.33
Wind Energy	M$	-	$ 0.97	$ 1.93
Storage	M$	-	$ -	$ 0.28
Tech/Proj.Mgmt Resources	M$	-	$ 0.96	$ 1.64
Total	**M$**	**-**	**$ 4.82**	**$ 8.18**
O&M Cost				
O&M Cost	M$	$ 3.73	$ 3.46	$ 3.30
O&M Cost Reduction+	**M$**	**-**	**$ 0.27**	**$ 0.43**

* Reduction compared to DGS Baseline

Bella Coola Example

- Remote microgrid 439 km north of Vancouver.
- Peak load: 3,800 kW
- RES: Hydro (700 + 1,420 kW)
- Diesel gen. sets: 7 (7,200 kW, less than 35% efficiency)
- Storage: electrolizer (300 kW) and FC (125kW), and “flow” batteries (125 kW) which have not been deployed.
- Designed to reduce diesel consumption by storing the energy available from the river’s seasonal variations.

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Bella Coola Example

- Run-of-the-river hydro:

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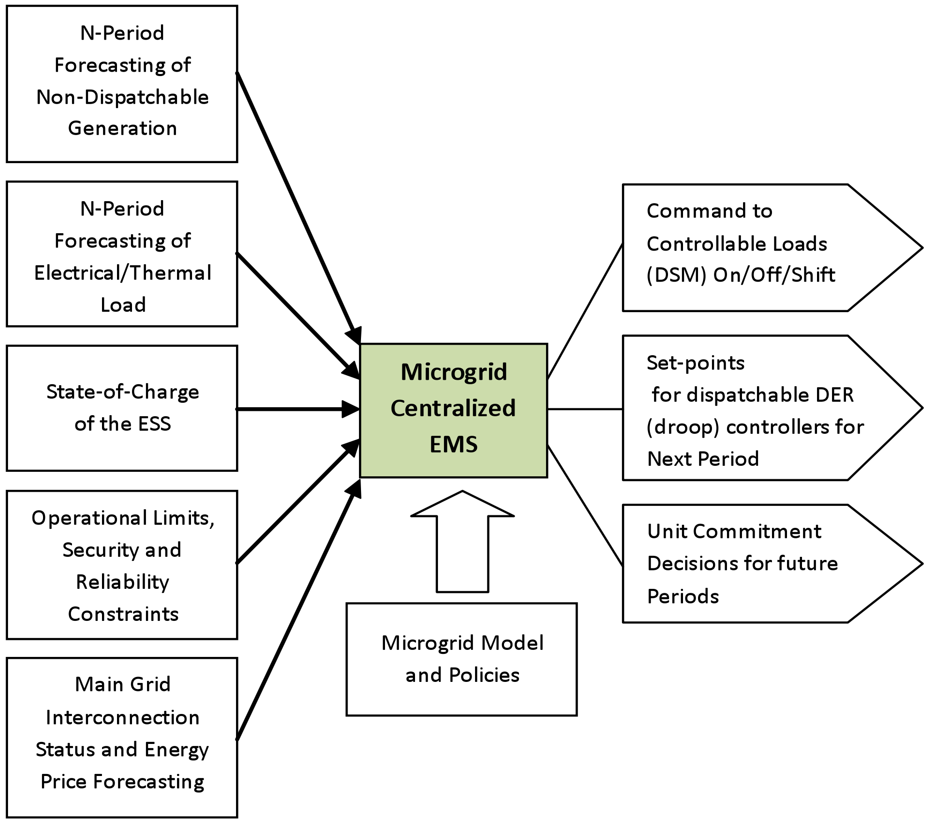
Bella Coola Example

- In microgrids, all the EMS applications must be performed by an autonomous automated system.
- The operation of an EMS in a microgrid becomes more challenging due to the critical demand-supply balance, low inertia of the system and the presence of energy storage systems.

Bella Coola Example

- The general EMS case:
  - Find the optimal or near optimal unit commitment of units.
  - Find the optimal or near optimal dispatch of units.
  - Find the optimal or near optimal voltage settings.
- Challenges for EMS in microgrids:
  - Intermittent and hard to predict generation.
  - System states are coupled in time due to Unit Commitment (UC) decisions and Energy Storage Systems (ESS).
  - Multiple objectives (e.g. total cost, GHG emissions)
  - Multiple owners and sometimes conflicting objectives.

Bella Coola Example



- Advantages:
  - Allows the implementation of traditional optimization methods.
  - Able to handle multi-period optimization.
  - More suitable for stand-alone operation, when demand-supply balance within the microgrid is critical.
- Disadvantages:
  - Obligates the different actors to share information about operation costs and constraints.
  - Difficult to implement in a multiple-owner microgrid with different and conflicting objectives.
  - The EMS needs to be re-adjusted when more units are added.

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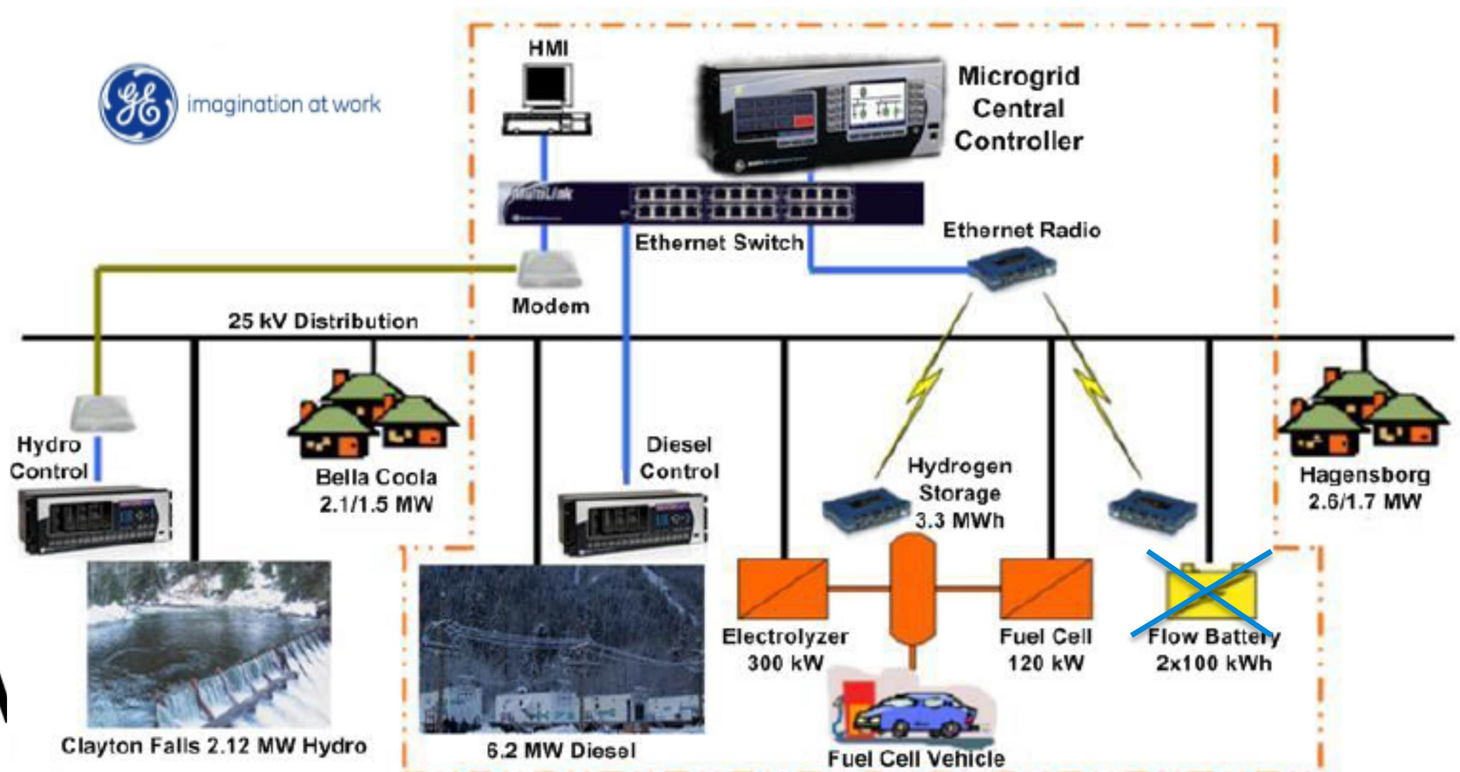
Bella Coola Example

- A centralized controller (MGC) by GE dispatches the diesel generators using an MPC approach:



Research at uWaterloo

- NRCAN's ecoEnergy II Project "Development of a utility grade controller for remote microgrids with high penetration renewable generation":
  - Address RE integration issues related to microgrid operation and control:
    - Microgrid controller development and lab testing by Hatch and UofT.
    - EMS, planning, control, and community studies at Waterloo.
    - KLFN studies and community engagement.
  - Partners: Hatch (lead), uWaterloo, UofT, Wenvor, KLFN, Hydro One.
  - Budget:
    - Total: ~$3M
    - NRCan funds: ~$2M
  - uWaterloo researchers:
    - Profs. Bhattacharya, Cañizares (uWaterloo PI), El-Saadany, Kazerani, and Parker.
    - 5 PhD, 2 MASc, 1 RA, and 1 PM involved.

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Conclusions

- There is a need to introduce RE in microgrids in Canada:
  - To reduce environmental impact.
  - To reduce operating costs.
  - To help address load growth restrictions.
- Challenges:
  - RE equipment, installation and O&M costs are significant.
  - Optimal planning tools are needed.
  - Automatic EMS and V and f control are necessary, considering the variability of RE resources.
  - Social aspects need to be considered, particularly community engagement on load management and microgrid O&M.